

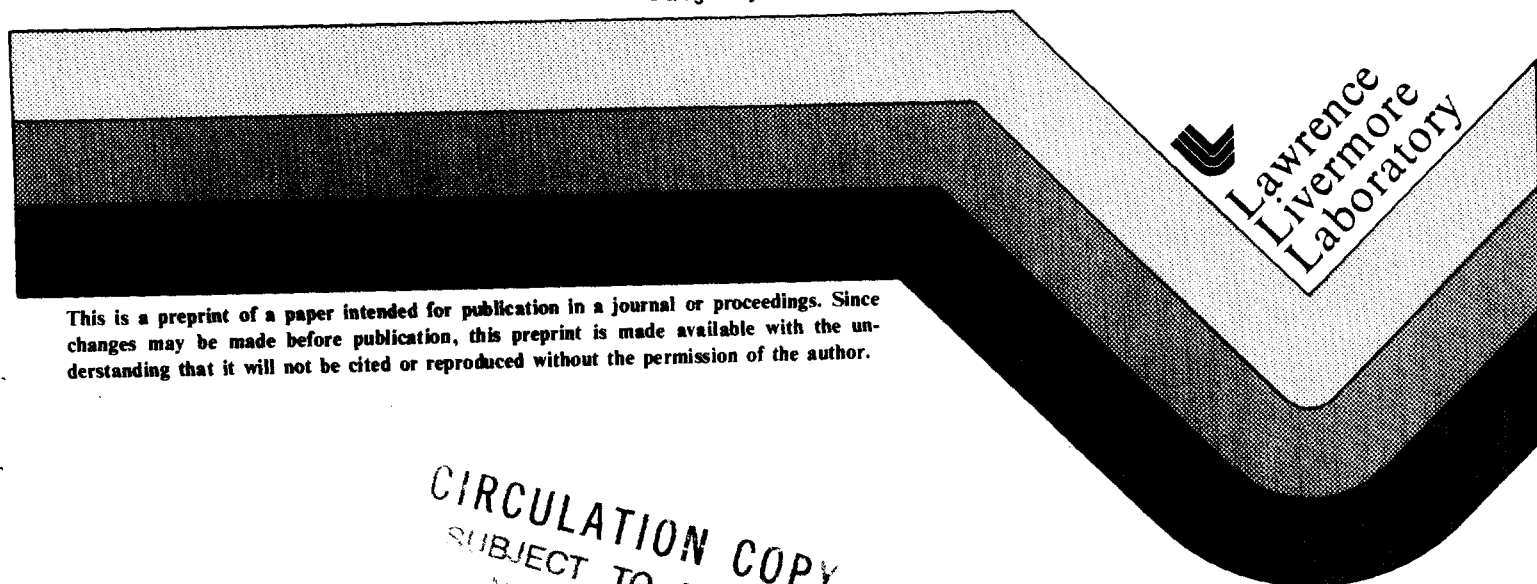
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Early Cavity Growth During Forward Burn

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ABSTRACT

During the early portion of the forward burn phase of the Hoe Creek III field experiment, the cavity propagated rapidly down the deviated borehole and to the top of the coal seam. As a first step to understanding this phenomena we have conducted small scale coal block experiments. Drying as well as combustion tests were performed. This paper describes the test hardware and the experimental results.

INTRODUCTION

During the early portion of the forward burn phase of the Hoe Creek III field experiment, the burn front propagated rapidly down the deviated borehole and to the top of the coal seam.¹ Concurrently with the burn propagation, intermittent particulate production occurred.

As a result of this phenomena both injection wells (A, P1) were damaged due to combined thermal and mechanical effects. This resulted in the movement of the oxygen injection point from near the bottom of the Felix #2 coal seam to the top of the Felix #2 coal seam. Injecting oxygen at the top of the coal seam resulted in the degradation of the product gas heating value as well as poor resource recovery due to heat losses to the overburden and override.

Two mechanisms were postulated for this propagation behavior. One is that the passage of hot gasses through the deviated borehole dries the coal and the coal then spalls and crumbles exposing fresh coal which in turn dries and crumbles. Progressive drying and crumbling moves the deviated borehole to the top of the coal seam. The other mechanism postulated was that the coal preferentially burns at the top of the cavity due to buoyant forces. This preference results in a continual upward evolution of the cavity as the forward burn proceeds.

To test these hypothesis and provide some explanation for the early time

behavior of the Hoe Creek III forward gasification we have devised some simple small scale reactor tests. Although we recognize the possible scaling problems we felt that small tests were a cost effective first step.

Both drying and combustion have been addressed and the following describes the test results.

EXPERIMENTATION

Drying Experiment

Our goal was to determine if upon drying at a relatively high temperature in a non-oxidizing atmosphere, the coal had a propensity to spall and crumble. If this were the case, then the particulate excursions as well as the early upgrowth of the cavity could be explained by coal drying with subsequent collapse.

To construct the necessary reactor we cut a standard 55 gallon drum in half. A coal* block was installed in the upper half and electrical resistance heaters in the lower half. Connectors were installed in the drum for injection and exhausting an inert purge gas as well as feed throughs for the thermocouples. Figure 1 depicts the reactor ready for test. Note that the coal block is unsupported and if spalling and crumbling occur, the particulates can fall away from the block thereby exposing fresh coal.

The total duration of the experiment was 25 hours. The temperature time-history of the exposed coal is shown in Figure 2.

*For this and subsequent reactor experiments, blocks of coal were collected at Kerr-McGee mine near Gillette, Wyoming. The coal blocks were trimmed to size, placed in water filled 55 gallon drums and shipped to Livermore. This Roland seam coal is 32.9% ash with a pseudo-molecule of $\text{CH}_{0.95}\text{O}_{0.19}\text{N}_{0.014}\text{S}_{0.004}$. $489\text{H}_2\text{O}$, which has a dry, ash-free molecular weight of 16.3. This coal is very similar to the Felix coal at Hoe Creek.

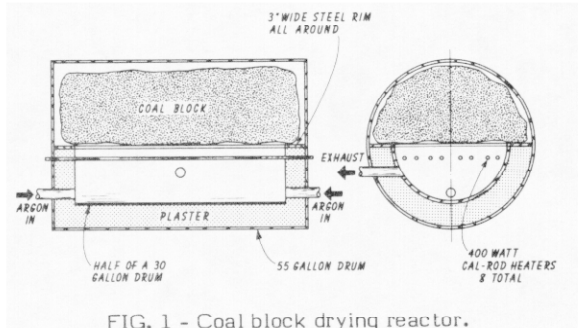


FIG. 1 - Coal block drying reactor.

To maintain an inert environmental during this thermal cycle, the drum was purged with 18 SCFH of argon gas.

Examination of the coal block after the temperature cycle indicated that there was no extensive spalling or crumbling. The surface was cracked and dried, but the coal was still self supporting. Some effort was required to break off chunks of the dried coal. We concluded that the coal in this geometry, at this scale, and under these conditions does not spall and crumble when dried in an inert atmosphere. Consequently, a simple drying model did not provide a satisfactory explanation for the cavity formation and particulate production observed during the Hoe Creek III experiment.

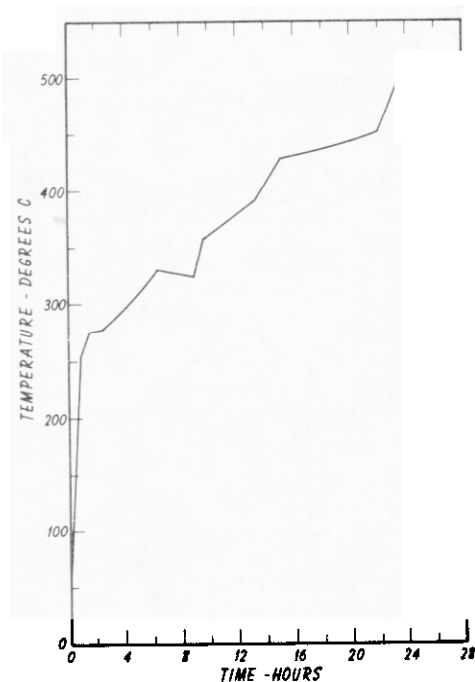


FIG. 2 - Temperature-time history for coal block drying.

Other drying experiments (smaller in scale) were performed based on the results of the combustion experiments. The results are detailed in the following sections.

Combustion Experiments

Five forward burn combustion experiments have been run to assess the effects of air and/or oxygen/steam at various flow rates on early cavity formation.

Again a block of coal is potted in a standard 55 gallon drum. Figure 3 is a pictorial of the reactor. Assembly is quite simple. After identification of the coal bedding plane the block is placed in the 55 gallon drum which in turn is marked to orient the bedding plane with respect to vertical. Plaster is then poured into the drum to fill the annular space between the coal block and the drum as well as the space top and bottom. A 1/4 inch hole is drilled through the block, which forms a channel down which the burn progresses. A short span (~7 inches) of this burnhole is reamed and a 1/4" stainless steel tube is potted in place using high temperature cement.* Along with the tube a resistance igniter is located at the tube exit which is used as the ignition source for the coal. Note that a thermowell is shown in Figure 3. This is used in conjunction with a moveable thermocouple to track the boundaries of the cavity as the burn progresses. Because of the simplicity of construction and ease of modification, more than one thermowell has been used in both the horizontal as well as vertical configuration.

The LLL Laboratory Coal Gasifier Facility metered the injection gas flows and recorded the temperatures for all the

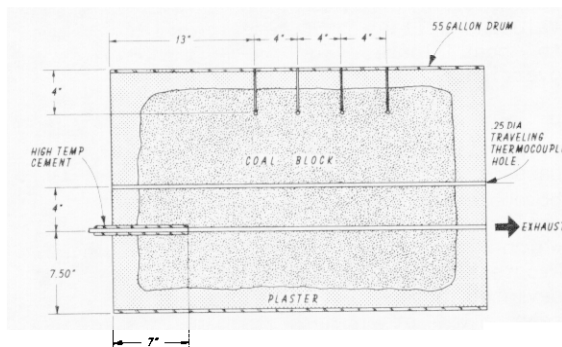


FIG. 3 - Cavity growth experiment reactor.

*35.5 wt/o Type I Portland Cement, 37.8 wt/o Silica flour, 0.1 wt/o TIC 26.6 wt/o water.

experiments.² The rate and temperature response data were collected and stored using a Hewlett Packard 21MX/E minicomputer at the facility. Temperature and flow rate data were processed in real time and results were displayed to aid in controlling the experiment.

RESULTS

To date five tests have been conducted. Table 1 summarizes the test program. Each test is identified along with the injectant(s), average flow rate and duration of test after ignition.

To characterize each test and for comparison purposes, after completion of the test the reactor is cut in two and the cavity examined. The pertinent dimensions of the free cavity formed as well as the approximate dimensions of the dried zone were obtained. These data are pictorially represented in Figures 4, 5, 7a and 7b for each of the tests both experiments 5 and 8 which were low flow produced essentially identical cavities although the injection was oxygen for 5 and air for 8. A cross section typical of both is shown in Figure 4. Note that the aspect ratio (height to width) is approximately 2:1 and the char zone is essentially zero at the top of the free cavity. These low flow tests provided some initial indication of how a cavity might form early on in a forward burn. It appears that the upward growth predominates.

Experiment 10 was a duplicate of Experiment 8 with the bedding planes rotated 90° from vertical. As can be seen in Fig. 5 the free cavity propagated horizontally faster than vertically. This indicates that at least in the Wyodak coal the burn tends to propagate faster perpendicular to the bedding planes than to them.

As a result of these first three tests we performed a simple drying test to test the hypothesis that the Wyodak coal when dried cracks in a preferential direction.

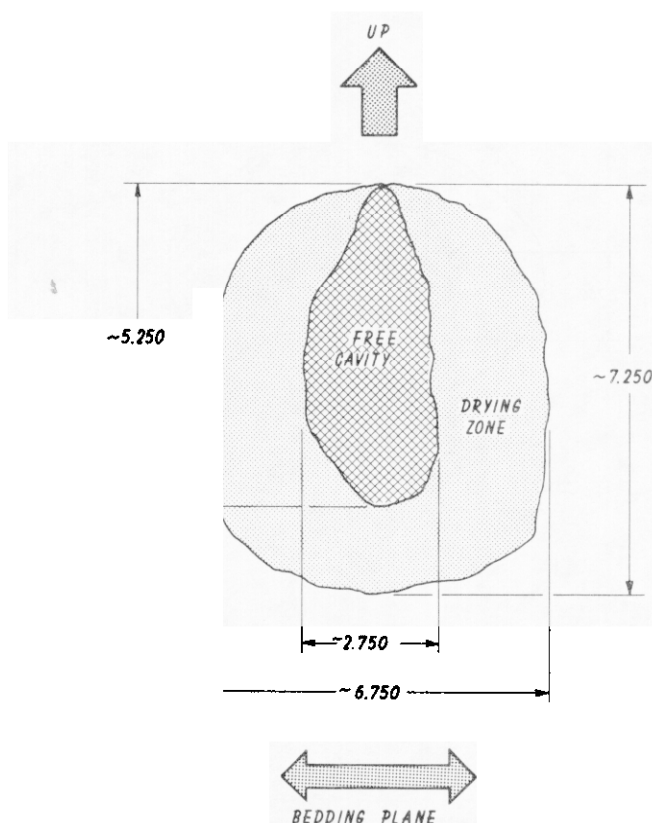


FIG. 4 - Typical cross section for low flow experiments (air or oxygen).

A smaller coal block was potted in a 5 gallon tin and a 1/4" diameter hole was drilled in it. A calrod heater was inserted and suitable plumbing attached to allow for an argon purge. The power was applied to the calrod and the temperature of the coal in the middle of the block was maintained at 500C for 8 hours. After the thermal cycle the block was cut in half. Figure 6 is a representation of this cross section. Examination of the dried coal around the pre-drilled hole indicates that

Table 1

Test Identification	Injectant	Flow Rate	Duration
Exp. 5	Oxygen	5 m-moles/sec	11.5 hours
Exp. 8	Air	25 m-moles/sec	10.5 hours
Exp. 10	Air	25 m-moles/sec	10.5 hours
Exp. 11	Air	120 m-moles/sec	3.5 hours
Exp. 12	O ₂ steam	25 m-mole/sec O ₂ 60 m-mole/sec steam	4.75 hours

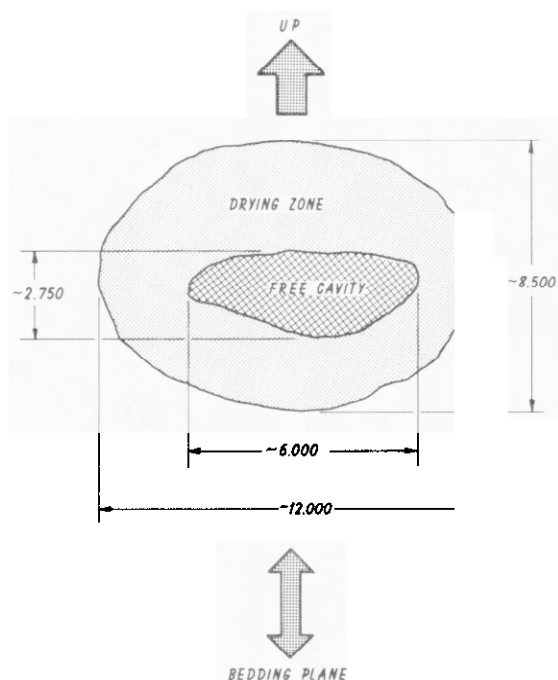


FIG. 5 - Cross section of cavity for low flow experiment with bedding plane coincident with vertical.

the coal exhibits an anisotropic behavior, i.e., the larger cracks were perpendicular to the bedding plane parallel with the cleat structure. This tends to explain the behavior of the pure oxygen burn as well as the air burn. The coal dries and contracts with the preferential crack growth perpendicular to the bedding planes. This crack appears to be a source of steam which in turn reacts with any char, that may have formed around the crack. This in turn exposes fresh coal which dries, cracks,

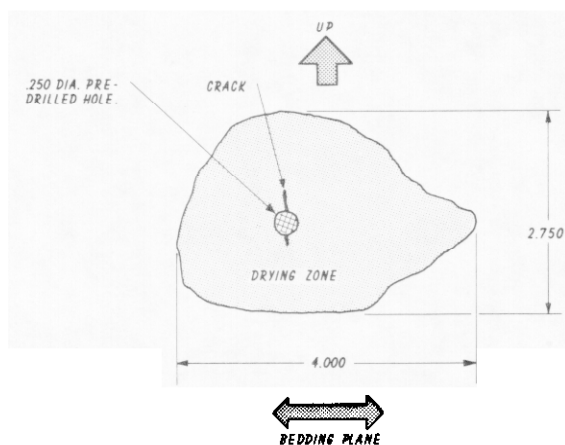


FIG. 6 - Cross section of drying experiment.

combusts, etc. This sequence results in preferential propagation of the cavity.

To confirm this under different flow regimes, two high flow tests were performed. One used air as the injectant and the other was a steam/oxygen burn. These were Experiment 11 and 12 respectively. Figures 7a and 7b depict the resultant cross section. Note that 7a, the air burn, looks very similar to the low flow test, i.e., a zone at the top of the cavity which contains little or no char and thicker char zones at the side. Figure 7b is more nearly circular with a rather uniform, thin char zone. These tests differed from the low flow tests in that growth was more symmetric with respect to the injection point. This suggests the lower flows allowed ash to accumulate on the floor which inhibited downward growth, while the higher flows effectively kept the floor clean.

During this last test (oxygen/steam) significant quantities of particulates were formed. Approximately one pound of particulates consisting of char, unreacted coal and ash were collected in a knock-out drum in the exhaust gas line. None of the four previous experiments produced any measurable quantities of particulates. This tentatively indicates that excess moisture (as steam) may provide a mechanism which results in the formation of particulates. These are in turn transported out of the reaction zone by the exhaust gas.

If this is the case then the early time particulate excursions observed during the Hoe Creek III (and Hoe Creek II) field experiment may have been aggravated by excessive ground water intrusion into the reaction zone.

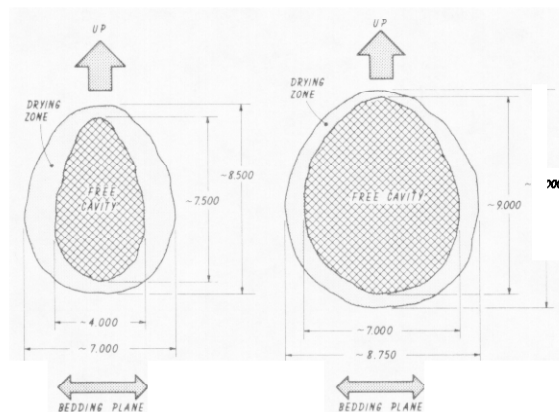


FIG. 7 - (a) Cross section for high flow air burn. (b) Cross section for high flow steam/oxygen burn.

CONCLUSION

As a result of these preliminary tests a possible mechanism for the early time performance of the Hoe Creek III field experiment may be inferred with respect to cavity growth and particulate excursions.

The Wyodak coal when dried cracks perpendicular to the bedding planes. This exposes fresh coal to the reaction which in turn leads to drying and further crack formation. This sequence results in an upward propagation of the cavity.

Excess moisture in the reaction zone may result in particulate formation. The reason for this may have to do with the steam/char reaction, but this is only conjecture at this time. Further experimentation may provide a satisfactory answer.

At the small scale used in these experiments, the cavity formed is empty. There is no bed of rubblized coal. The cavity formed is long with a high arched roof. Larger tests will be needed to determine the ultimate size possible for such a cavity before roof collapse occurs.

Small scale coal block experiments have provided some insight into early performance of the field experiments conducted at the Hoe Creek site. Further endeavors are planned using other coals and larger blocks with the goal of understanding the "in-situ" process and the effects of local hydrology and lithology on that process.

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